A

Comments from Arthur D Little Inc.

In the matter of:

Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems

Docket 98-153

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Secretary Secretary's name

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1 SUMMARY

Arthur D Little (ADL) is an engineering and consulting company in the based in Cambridge, MA, but with business worldwide. ADL's turnover in 1997 exceeded $450 million, of which technology and product development contributed over $100M, creating additional turnover for our customers estimated at over $10Bn, in telecommunications, engineering, healthcare, other industries and government.

Among many radio and radar activities, we have 18 years' experience in the development of wideband radar systems including ground and ice penetrating radar, fluid level sensing, collision warning and missile scoring systems, which we manufacture for the US Navy, UK MOD, French DGA and Australian RAAF. We are able to judge the appropriateness of UWB solutions in meeting developing needs, in the context of other electromagnetic systems.

As manufacturing techniques improve, and costs fall, this technology is becoming ripe for broader commercial applications.

ADL's interest is in the opportunity to develop products to be sold and used in large volumes, using Ultra Wideband (UWB) technology. These opportunities are primarily in the automotive, industrial and domestic appliance markets. A fundamental issue facing such opportunities is the need to comply with appropriate standards.

We welcome the Commission's Notice of Inquiry (NOI) as an opportunity to discuss the technical and commercial issues in the use of UWB devices. The use of the radio spectrum is evolving, and the design of equipment able to make flexible use of different frequencies and waveforms will continue to advance.

Consultative processes of this kind are welcome and essential, and will help to ensure that the US leads in the development of new technology and its application, and providing opportunities for economic growth of US businesses.

2 APPLICATIONS AND BENEFITS TO INDUSTRY AND USERS

A number of petitions for waiver of the FCC rules[1] have been made recently concerning equipment that will be restricted to low volumes (approximately hundreds of units).

We would like to focus our comments on applications with the widest potential to provide benefits to users and hence opportunities for American businesses, and for which waivers would be an inappropriate mechanism. Significant economic benefit could be derived by providing regulations which permit the operation of these devices in an unrestricted way, subject to simple standards which ensure that they will be benign with respect to other services.

[1] Notice of Inquiry in the matter of Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems (FCC 98-208)

The market for these devices will be worldwide, and we are therefore monitoring closely the evolving European regulatory situation, with our UK subsidiary, Cambridge Consultants Ltd.

New European regulations for approval of these types of device are also in the early stages of discussion. An informed decision concerning an approvals route in the US would influence those discussions, and provide an opportunity for American companies to be well placed to take advantage of European markets.

- **Market Perspective**

The potential applications for UWB systems are shown below with projected volumes for the US market and a note on the particular benefit of radar solutions. The automotive industry has identified radar based sensing as key to the development of advanced collision warning and avoidance systems. Interest in UWB systems is particularly strong as they typically use frequencies below 10GHz and hence provide the basis for lower cost solutions than millimetric sensors at 24 or 77GHz.

Application	Volume (‘000s per annum)	Introduction Date	Unit price ($)	Principle Advantage of UWB Based Sensing
Car Security	250	2001	25	Well defined detection area
Occupant Sensing (airbag)	>500	2003 – 2006	50	Fast update rate, false target rejection
Vehicle Reversing Aid	2000	2003	100	Longer range than ultra-sonic sensors
Vehicle Collision Warning	1000	2006	100	Cost advantage over higher frequency systems
Ground Penetrating Radar	10	2003	2,000	Improved detection of plastic pipes over existing acoustic and LF electromagnetic techniques
Industrial Level Measurement	10	2001	1,000	Stable, non-contact measurement
Industrial Proximity Control	>50	2001	10	Insensitive to dust and dirt
Missile Scoring	0.1	1980	20,000	High accuracy, “low” cost

Table 1: Applications of UWB Radar based Sensors

- **Guideline Frequency Characteristics**

A guide for the likely frequency range of interest for the different types of system is shown in Table 2. It should be noted that this an outline guide only, and that the necessary bandwidth required for each application will be a function of the desired range resolution (many in-air applications can function with a bandwidth of 1GHz). The figures shown reflect the fundamental limitations of applying radar techniques to the applications.

Application	Frequency Range (MHz)	Total Power Levels (EIRP)	Spectral power density levels (EIRP)	Range (m)
Car Security System	1000 - 10000	-20dBm	-50dBm/MHz	< 2 metres
Occupant Sensing (airbags)	1000 – 10000	-20dBm	-50dBm/MHz	< 2 metres
Vehicle Reversing Aid	1000 – 10000	-10dBm	-40dBm/MHz	6 metres
Vehicle Collision Warning	1000 – 10000	+20dBm	-10dBm/MHz	< 30 metres
Ground Penetrating Radar	50 – 5000	+20dBm	-10dBm/MHz	< 3 metres
Industrial Level Measurement	1000 – 10000	-10dBm	-40dBm/MHz	< 30 metres
Industrial Proximity Control	1000 – 10000	-10dBm	-40dBm/MHz	5 metres
Missile Scoring	300 – 900	+20dBm	0dBm/MHz	50 metres

Table 2: Guideline Frequency Characteristics

3 REGULATORY TREATMENT

The following section provides a response to the particular questions referenced in the Notice Of Inquiry (NOI).

- **Should certain types of UWB Systems be Licensed ?**

Our view is that licensing should be limited to low volume, higher power applications, where a single device has the potential to cause significant interference with many other devices. Our interpretation is that no other rule parts appear to be appropriate to UWB devices.

We believe that the principle adopted should be that UWB devices should operate such that they should not cause harmful interference to existing services and that they accept any harmful interference from existing services and from other operations authorised under Part 15.

- **Definition of Ultra Wideband (UWB) Devices**

We are aware that a number of definitions exist for UWB systems[2] [3], which relate to placing a lower limit on the fractional bandwidth.

In practice, the bandwidth of operation will need to be limited for applications where received interference is likely, and reliable operation is a prerequisite (e.g. automotive applications). In many applications, there is also a requirement for compact, low cost antennas which will also limit the transmitted and received frequencies and bandwidths.

Many of the advantages of these systems (high resolution, low probability of mutual interference) can still be achieved with wide bandwidths but not ultra-wide fractional bandwidths, but are still constrained in application by existing regulations. There would therefore be an argument for including signals which reduce their occupancy by spreading power evenly, but do not have to have very high fractional bandwidth. An actual bandwidth of >1GHz could be a qualifying figure.

It may also be difficult to measure and verify what the device bandwidth is (since power levels are very low, and receiver processing gain is not externally accessible).

The term "fractional bandwidth" should be defined as follows:

> **Fractional bandwidth**. The ratio Bf defined by the expression $2(f_H - f_L) / (f_H + f_L)$ in which f_H is defined as the highest frequency limit and f_L is defined as the lowest frequency limit, which mark the frequencies that are 20 dB below the maximum of the power spectral density envelope.

There is an argument, based on simplicity, for simply limiting spectral power density overall, rather than defining what is or is not an ultra-wideband system. This would avoid difficult measurements, would satisfy all the arguments which are made in favor of these devices, and would provide the greatest incentive for innovative use of the spectrum, which might otherwise be thwarted by a premature restriction on the equipment type.

However, it is probably prudent to regard this as a first step towards the liberalization of the spectrum for low-power devices, and to apply a standard by which to select appropriate, well-characterised systems for such a step. A figure of Bf>0.25 OR B>1GHz could be used as the criterion, unless power levels are so low as to defeat measurement.

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[2] Assessment of Ultra-Wideband (UWB) Technology, OSD/DARPA Ultra-Wideband Radar Review Panel, R-6280, Defense Advanced Research Projects Agency (July 13, 1990)
[3] Introduction to Ultra-Wideband Radar Systems, James D Taylor, ed., CRC Press (1995)

4 TV AND RESTRICTED BANDS

- **Should the rules generally continue to prohibit operation of UWB systems within the restricted bands and the TV broadcast bands?**

A missile scoring system manufactured by Arthur D Little, AN/DSQ-57, is used by the US Navy under J12 authorisation 4066, operating in the band 300-900MHz. This successfully uses a frequency interleaving technique to avoid interference to or from TV systems. This is an infrequent application, with only tens of systems in use worldwide. This equipment has been exhaustively tested and has not caused known interference. However, large numbers or uncontrolled but similar emitters should be treated with caution.

In the case of GPR systems which are likely to operate in this band, a requirement that the unit must only be operated in contact with the ground, and tested accordingly should result in a very low level of radiated emissions due to the absorption of the ground. Appropriate emission levels however will have to be defined, taking into account the relatively small number of systems which should be expected.

If the power levels needed for useful UWB systems can be shown to lead reliably to innocuous operation at any part of the spectrum, then consideration should be given to lifting restrictions there.

- **Are there certain restricted bands where operation could be permitted, but not others? If so, which bands and what is the justification?**

Interference in certain restricted bands may carry more serious consequences than in others, and different criteria are deemed necessary in those bands. We are not familiar with the precise reasons for selecting Restricted Bands, and therefore would not be justified in asserting that this protection of a particular band could be dispensed with.

However we can comment in general terms as follows:

In bands where the function of an essential, authorised service were dependent on maintaining only a low positive signal to thermal noise ratio, the operation of these UWB systems would appear like an increase in the noise temperature and could then degrade performance. This might appear to be the case for radio astronomy, but distance and high antenna gains would cause the present limits to appear conservative.

In bands where the receivers are designed primarily to reject interference from other emitters at higher levels, there will be no appreciable effect and UWB systems could be tolerated.

It is our belief that at a certain level of emitted signal power density, the level of added noise will be well-defined and acceptable in most bands.

In practice, for almost all applications of UWB radars, except in certain military applications, operation below 100MHz is precluded by the size of antennas required. Restricted bands below this frequency are therefore of less commercial concern.

- **If Restricted Bands were retained, what effect would this have on the viability of UWB Technology?**

According to the definition of Restricted Bands, the emission of any signal within these bands which contributes to the function of the device is forbidden.

Systems can be conceived which operate with a necessary bandwidth and spectrum nominally outside the restricted bands. The band from 5.46GHz to 7.25GHz provides adequate bandwidth for certain functions for which ultra-wideband solutions may be considered. However the large number of restricted bands and the zero permitted level of non-spurious emissions makes genuine ultra-wideband operation impossible.

Spurious emissions (47 CFR Subpart A §2.1) are permitted in these bands and are uncontrolled in content (for example, in the case of digital devices). In practice these cause few observed problems, and we recommend that any new regulatory action should open as many Restricted Bands as possible to intentional emissions at similar levels.

Compliance with existing restricted bands within an otherwise full spectrum would require the introduction of band reject filters. This has a significant effect on the impulse response of these systems, in the form of time-extended oscillatory behaviour. In radar applications this can cause serious degradation of performance, since such time extensions are equivalent to high-level clutter returns. Additional signal processing may be required, or the application may be infeasible.

The retention of all restricted bands with present definitions and limits will continue to prevent the development of viable UWB products, either from a regulatory or a cost standpoint. Further restrictions would exacerbate this situation.

5 EMISSION LIMITS

- **Are existing general emission limits sufficient to protect other users?**

Spurious emissions are controlled under the existing rules and limits, and in general are suppressed by good engineering design practice and without requiring extensive specific filtering. They do not result in notable interference problems at present. This is strong evidence that even large numbers of systems, which may radiate unintentionally up to these controlled levels, are benign with respect to existing communications and sensor (radar, astronomical or other) systems.

Provided that certification procedures ensure that emitted spectra are known, smooth and steady, as measured with appropriately chosen instruments and tests, UWB systems at these levels should also be benign.

- **Should different limits be applied to UWB systems?**

General emission limits cater for emissions of many kinds, including those with 60Hz and harmonic periodicities which can result in intrusive interference. It is possible that properly specified and designed UWB systems (for instance, where the smoothness or regularity of the spectrum were specified) could be permitted to operate at higher levels without objectionable effects. However, this would require significant research and more comprehensive regulatory provisions. We recommend that any higher limit should be considered when significant experience has been gained with operation of these systems at existing general emission limits. An overambitious change would be very damaging to all parties.

We can calculate the effect of emissions at the level of existing general limits. For a known emitted power density, we can define a minimum distance beyond which another system is unlikely to suffer interference as a function of frequency, because the received power becomes less than the thermal noise power of the receiver. This distance will be a conservative estimate of the safe separation, since it ignores processing gain available in the "victim" receiver.

Sample Calculation:

The emission level equivalent to the provision of 15.209 is:

Frequency (MHz)	**Power Density (per MHz BW)**
216-960MHz	12nW
Above 960MHz	75nW

Table 3: Emission Levels

The test bandwidth is stated as a minimum of 1MHz. A wideband transmitter which meets this limit will have a spectral power density as shown in Table 3.

We consider the distance at which the level of power received falls below thermal noise in a receiver with an isotropic antenna (0dBi) and a noise figure of 6dB, and with the receiver at the peak of the emitter's beam. Provided we measure receiver noise and interference over the same bandwidth. A conservative estimate of the maximum distance at which another device will see interference is shown in Table 4.

Frequency	Distance
500MHz	40 metres
960MHz	20 metres
1000MHz	50 metres
2.45GHz	20 metres
5GHz	10 metres

Table 4: Range for interference to fall below victim's thermal noise

Since the majority of receiving equipment exhibits a degree of processing gain, these figures may be conservative. They suggest that applications where the devices are separated normally by 10 metres or more, wideband applications above 5GHz will be reliably benign at these levels. They do not support any substantial increase in the permitted levels except for more widely-dispersed transmitters. A more detailed investigation would provide additional confidence.

- **Should the standard be expressed as a spectral power density?**

A standard expressed explicitly in terms of spectral power density would be appropriate for these devices.

- **Should these standards be designed to ensure that the emissions appear to be broadband noise?**

In general, noise-like characteristics in the frequency domain may be the most acceptable.

In the case of J12 4066 we have shown that an alternative scheme, that of frequency interleaving, can also be effective. This is used in a specialised application, and should not provide the basis for general authorisation.

- **What is the potential for interference if there is a large proliferation of UWB devices?**

UWB devices are in part attractive because they can be made at low cost. However, to our knowledge, no test results are available on the effects of deploying many UWB systems. Each application area shown in Table 1 will have different usage densities and profiles.

The area with the largest potential volume is in the automotive industry. The introduction of more electronic systems on vehicles has raised the profile of compatibility issues, and will be considered in the selection of an appropriate frequency range for the UWB system.

Considering the three cases shown, the usage profiles and equipment design provide a basis for estimating the potential for interference:

Application	Volume ('000 pa)	Introduction Date	Notes
Car Security System	250	2001	i) Interior to vehicle ii) Short Range
Airbag Occupant Sensing	>500	2003 – 2006	iii) Interior to vehicle iv) Uses directional antenna illuminating occupant v) Short range
Vehicle Reversing Aid	2000	2003	i) Only selected when reversing ii) Uses ~90^{o} antenna coverage
Vehicle Collision Avoidance	1000	2006+	i) Operating continuously ii) Uses broad antenna coverage iii) May be narrower band

Table 5: Usage Profiles for Automotive Applications

Care must be taken in modelling the effect of multiple RF devices. However, extremely high densities of these devices would be needed to produce any appreciable build-up of ambient noise.

The effect of devices at distances much greater than those shown in Table 4 will be limited for ground-based receivers not only by the inverse-square propagation law but also by shadowing, refraction and dielectric absorption in buildings and in propagation along the ground. Therefore only the few devices which may be within these ranges need be taken into account. Air- or space-borne receivers are discussed in the next section.

The most important consideration for the designer will be the mutual compatibility of these systems, which can be provided by appropriate timing control and gating.

- **Could the cumulative impact result in an unacceptably high increase in the background noise level?**

The effect of large numbers of emitters might be seen by more remote receivers e.g. satellite radar receivers or airborne telemetry equipment. We can calculate an example of the effect an accumulation of such devices might have.

Sample Calculation:

Consider a parking lot 100 metres square, containing 500 cars in which 20% of the cars are operating a UWB reversing aid in the 5GHz region, using transmitters with a mean EIRP in the direction of the receiver of 25nW per MHz of bandwidth. The receiver will not be on the boresight of all transmitters. The transmitters will sum incoherently, and will represent a total effective output of 2.5uW per MHz.

Assuming the receiver is 1km distant, and using a 20dB receiver antenna gain (to focus on the lot), the received signal would be approximately 4dB below thermal noise in the same bandwidth:

$$Pr/Pn = Pt * Gr * (\lambda\hat{}2/4\pi) / ((4\pi * R\hat{}2) * (kTB)) \text{, using conventional notation}$$

An isotropic receiver might "see" 100 times as many cars but with similarly reduced gain.

These simple examples do not provide a quantitative case, but suggest that appropriate constraints can result in benign operation of many devices, whilst retaining considerable benefits to their users. Other bodies have carried out more detailed technical evaluations of noise aggregation[4]. However, care is needed in setting up models of complex assemblies of emitters.

- **Should the Commission limit proliferation by restricting the types of products or should the rules permit manufacturers to design products for any application as long as the equipment meets the standards?**

The greatest economic value of this technology is likely to be in large-volume applications. This will permit the price of UWB devices for all applications to fall. Applications of this technology are numerous and any restriction to specific uses could impede the introduction of innovative products, reduce potential revenues for and jobs in American companies, and appear discriminatory.

It will be disadvantageous to set a restriction except on the basis of meeting individual emissions standards.

- **Should a limit on the total peak level apply to UWB devices?**

Careful attention needs to be paid to the language used in describing limits, in view of the different domains and measurements in which words may be used. The word "peak" may have at least four meanings depending on whether it is the maximum of a spectrum, a corrected "quasi-peak" spectral measurement, the mean power during the "on" section of an intermittent pulse train, or V^2/Z where V is the absolute peak voltage.

The interaction with non-linear receiver circuits (eg. Automatic Gain Control (AGC) or noise gates) needs to be considered.

For communications systems, a high-dynamic-range input circuit is generally followed by a filtering function which will narrow the bandwidth and smooth out the time domain response to a wideband system. The effect will be well characterised by the overall low-level noise-like description.

Other systems may have more susceptible low-dynamic-range receiver circuits. The effect of such signals on CDMA communications, with its tight control of power levels, might be an example; however, CDMA is an example of a modern system with significant receiver

[4] "An Analysis of Noise Aggregation from Multiple Distributed RF Emitters" WC Lynch, K Rahardja, S Gehring, Interval Research Corporation, November 1998.

processing gain, which should be able to co-exist successfully with low-power UWB systems.

The spectral power density, and its interaction with any restricted bands, is the proper characteristic to which to apply a general limit.

- **Can emissions below or above a certain frequency range be further filtered to reduce the potential for interference to other users of the radio spectrum without affecting the performance of the UWB systems?**

Certain applications are significantly affected by any severe band-limiting filters. Ground penetration is most effective when using a waveform close to a single cycle, tending to preclude a high degree of filtering within the desired band.

UWB missile scoring is achieved with significant band-limiting; in that case 3dB bandwidths have been successfully reduced to about half the frequency of maximum power density. Associated filtering provides essential protection to other target systems, and also protects the UWB system from external interference.

For other applications in free space or air, our experience is that compromises can be accepted in applying filtering, and frequencies below 1GHz can be excluded.

As an example, a bandwidth of 1GHz at a centre frequency of 6.5GHz appears to be sufficient for certain automotive radar applications. Although this might not strictly meet earlier definitions of an ultra-wideband radar, and can be made consistent with the existing provisions of Part 15, a manufacturer would benefit from language clearly oriented towards regulating, testing and authorising such a device.

- **Are the existing limits on the amount of energy permitted to be conducted back onto the AC power lines appropriate for UWB devices?**

We have gained experience through the engineering of missile scoring systems, which has demonstrated that good practice in power circuit design can cope with UWB signal transients within the existing conducted emissions limits.

Automotive applications will be subject to the appropriate specifications for conducted emissions defined by the vehicle manufacturer.

Existing limits appear to be appropriate.

- **What operational restrictions, if any, should be required to protect existing users?**

If emissions limits were to be raised for certain applications, this might be made dependent on operational restrictions such as where the device could be operated, or whether operation can be restricted (e.g. the use of ground contact switches for GPR systems, or maximum beamwidths and minimum speeds of operation for collision warning devices).

- **Is the use of UWB modulation techniques necessary for certain types of communication systems; if so, for what purposes?**

Communications systems of this kind can be constructed to exhibit good low-probability-of-intercept and high security. UWB techniques may provide a low cost solution for these needs.

6 MEASUREMENTS

- **Is a pulse desensitization correction factor appropriate for measuring emissions from a UWB device?**

Most UWB devices generate pulses which are low in amplitude, very short, and at rates which are high compared with the bandwidths of potential victim receivers. In these cases measured spectra are generally accurate and pulse desensitization of the receiver or the measurement does not occur.

Pulse desensitization is only likely to occur for low-rate, high-power devices such as spark transmitters, which we would seek to exclude through a pulse interval or peak voltage limit.

- **Should any modifications be made to this measurement procedure for UWB devices?**

Pulse desensitization correction is unnecessary for such pulses, and should therefore be removed from the procedure.

- **Would another measurement procedure that does not apply a pulse desensitization correction factor be more appropriate for determining the interference potential of an UWB device?**

A normal spectral power density limit will be adequate to protect equipment from interference by these low-power systems unless the victim receiver has a similarly broad bandwidth and a low dynamic range.

It may be desirable to exclude low-rate, high-power pulses which meet the spectral power density measurement by adding a pulse interval measurement and a peak voltage measurement.

- **The frequency range over which measurements are required to be made depends on the frequency of the fundamental emission. Is the frequency of the fundamental emission readily discernible for UWB devices?**

The current test procedure requires the spectral shape to be measured. Most ultra-wideband systems exhibit a clear but not sharp peak in their emission spectrum. However, systems will probably emerge which use more than one “maximum power frequency”, or exhibit a non-monotonic frequency profile. Hence systems are likely to fall across boundaries if hard limits are specified, and appropriate wording is needed.

Multiple peaks may be handled by applying different test procedures for different frequency regions.

- **Are the current frequency measurement ranges specified in the rules appropriate for UWB devices or should these ranges be modified?**

They appear to be appropriate.

- **Are the measurement detector functions and bandwidths appropriate for UWB devices? Should these standards be modified and, if so, how?**

Subject to instituting a power density limit, these are appropriate except for cases where time domain measurements (pulse interval, peak voltage) might be needed, where high powers occur at low pulse rates.

- **Are there any other changes to the measurement procedures that should be applied to UWB devices?**

No.

7 OTHER MATTERS

- **Should the prohibition against Class B, damped wave emissions apply to UWB systems or is the prohibition irrelevant, especially in light of the relatively low power levels employed by UWB devices?**

This provision is probably obsolete, and is irrelevant if the spectral power density limit is applied with a voltage or E-field measurement for low rate signals.

- **Comments are invited on any other matters or issues that may be pertinent to the operation of UWB systems.**

The use of the spectrum is evolving, and the design of equipment able to make flexible use of different frequencies and waveforms will continue to advance. Costs will continue to fall and numbers of users to escalate. Consultative processes of this kind are welcome and essential, and should be maintained to ensure that the US is leading in the development of new technology and its application.